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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

NATIONAL RESEARCH ON SPACE DEBRIS

SAFETY OF NUCLEAR-POWERED SATELLITES

PROBLEMS OF COLLISIONS OF NUCLEAR-POWER SOURCES WITH SPACE DEBRIS

Note by the Secretariat

Addendum

The Secretary-General addressed a note verbale, dated 13 July 1994, to all Member States inviting them to communicate information on national research on space debris, safety of nuclear-powered satellites and problems of collisions of nuclear-power sources with space debris.

The present document contains information provided in replies received from Member States between 1 December 1994 and 12 January 1995.

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REPLIES RECEIVED FROM MEMBER STATES

Germany

Original: [English]

Recognizing that space debris is a problem of high and rising concern to all spacefaring nations, the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS) began its deliberations on this subject as a separate agenda item in 1994. Germany expressly welcomed this step, since the German delegation to the United Nations (COPUOS) has throughout the debate on nuclear-powered satellites helped to prepare for this important step.

Germany is willing to contribute significantly to the discussions under the agenda item on space debris. In this respect Germany made a presentation on "Space debris - A review of scientific and technical aspects" during the 1994 session of the Scientific and Technical Subcommittee. Germany will also continue to submit annual reports on national research activities in this field; the latest report is contained in document A/AC.105/565/Add.2 of 23 February 1994. The present paper reports on the work done since then.

In order to cover the broad range of German research activities in the field of space debris, the German Space Agency (DARA) holds annual workshops[1] to exchange the most recent results of research and to shape the space debris strategy of DARA. An outline of this strategy is given in part I of the present report.

German research activities are either conducted on a purely national footing or are funded under contracts with the European Space Research and Technology Centre (ESTEC) and the European Space Operations Centre (ESOC) of the European Space Agency (ESA). The nationally funded research activities are largely concentrated in (a) the Institute for Space Flight Technology and Nuclear Reactor Technology of the Technical University of Braunschweig (IfRR/TUBS); and (b) the Research Establishment for Applied Science of Wachtberg-Werthhoven (FGAN) under research contracts awarded by DARA and ESA.

A brief outline of the work done by these two institutes is as follows:

(a) Modelling and model validation activities as well as studies to use the model for the assessment of mitigation measures have been continued at IfRR/TUBS, at a reduced level though, according to overall DARA financial restrictions. More detailed traffic models for future missions and various time steps for mitigation measures are implemented into the model to support the German attitude to international discussions in the field. The work of IfRR/TUBS for ESA to establish the Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) Model was successfully carried on. This new three-dimensional model will be available to users early in 1995;[2,3,4,5]

(b) Studies at FGAN related to space debris are aiming primarily at the investigation and development of radar techniques and analysis methods to detect, classify and identify space objects in low Earth orbits (LEO), geostationary orbits (GSO) and geostationary transfer orbits (GTO).[6,7,8] Radar measurements of selected space objects are obtained in the tracking mode of operations using the Tracking and Imaging Radar (TIRA). From these data the physical properties (i.e. size, shape, dimensions, intrinsic motion, mass, orbit and orbital lifetime) are derived. Radar observations of defined space volumes in a beam-park mode of operation are providing data on the population density. For model validation this information can be compared with results from space debris environmental models. The activities are funded mainly by DARA and ESA/ESOC.

This information is complemented by more detailed descriptions under sections A and B below.

A. Space debris strategy of the German Space Agency

In the past, Germany was involved in almost every field of debris activities, not least because of German leadership in the COLUMBUS programme. Therefore, know-how and competence have been built on and it is intended to maintain these. Reduced financial budgets of future space activities require a new strategy for space debris activities in Germany. This strategy distinguishes between national activities and contribution to ESA activities as well as international cooperation.

The nationally funded special areas in order of priority are as follows:

(a) Development of verification methods:

(i) Investigations of the phenomena of debris impact;

(ii) Establishment of data bases to catalogue available test results;

(b) Development of protection measures (protection systems and collision avoidance);

(c) Development of debris avoidance strategies.

Ideas and concepts for the removal of debris will be observed and separate ideas or suggestions, if any, will be contributed.

Integrated into this approach is the support for debris monitoring, recording and modelling, although these activities are considered to be part of international cooperation, especially participation in ESA programmes. Closer cooperation with ESA, as a goal of the German Space Agency, has been initiated by ESA with space debris coordination meetings held on 9 March and 28 September 1994.

The cooperation between the National Aeronautics and Space Administration (NASA) and DARA will be continued, and other bi- and multilateral possibilities of cooperation will be increasingly pursued.

B. Space debris modelling and prevention

Space debris modelling

Assessing the collision risk between a space debris object and an orbiting satellite has become one of the safety relevant design criteria not only for manned space missions but also for some satellites. A reliable database describing the debris population is only available for a minor part of the population, about 7,300 larger objects, whereas the characterization of the larger risk posed by the untrackable population is subject to debris modelling. These models are based on the simulation of all in-orbit fragmentations and are supported by a number of actual measurements. The ESA MASTER is currently under development at the Institute of Space Flight Technology and Nuclear Reactor Technology (IfRR) at the Technical University of Braunschweig under contract to ESOC (10453/93/D/CS). The development is in the final stages, the finalization and distribution of the model are scheduled for early 1995. The model will provide a huge background of information to users with an engineering, scientific or political background.

The purpose of the ESA MASTER model is the characterization of the natural and the man-made particulate environment of the Earth and the resulting threat to space missions. It is based on semi-deterministic modelling techniques and covers the size range above 100 µm (0.1 mm), where impacting objects may cause damage to spacecraft. The MASTER model offers a full three-dimensional description of the area surrounding the Earth up to the GEO region and is able to trace the characteristics (source, orbit,

mass, size) of all contributing objects. A break-up model, which is backed by fragmentation experiments of scaled upper stage models, has been used for the generation of the untrackable debris population resulting from all known in-orbit fragmentations (116 up to 07/93). The observable part of the population is considered by the implementation of ground-based measurements. The distribution of eccentricities and inclinations of the objects larger than 1 cm as modelled by MASTER illustrates the dominance of objects from the inclination bands from 60°-65°, at 82° and at about 100°, reflecting the occurrence of the major part of all fragmentation events in these bands. A considerable number of objects, most of them in the 60°-65° inclination band, can be observed in high eccentric (ε >0.1) orbits.

Intention of the MASTER model

The MASTER model has been developed under the requirement of a most efficient model/user interface and combines a vast amount of offered information with a very efficient storage and CPU time application in either a PC or workstation environment. The model consists of an Analyst Application with full orbit and flux information and a faster, slightly simplified Engineering Application. Both branches will be distributed on a single CD ROM. The model makes the advantages of a very complex semi-deterministic debris model available to users with restricted CPU-time and storage possibilities. It has been designed as a tool:

(a) To provide high resolution debris and meteoroid flux data. The Analyst Application offers a large quantity of information up to details about single target debris collision events including the location and geometry of the encounter and the source of the impacting debris object on any user defined orbit. In contrast to the Analyst Application, the Engineering Application is restricted to near circular target orbits. Both applications consider elliptical debris orbits;

(b) To offer a simple model/user interface. The whole model including a simple graphics module to visualize the standard model output will be distributed together on a single CD ROM. It can be operated on any MS-DOS PC, MacIntosh PC (System 7), IBM RS 6000 Workstations (IBM AIX) and on Sun Workstations with SUN OS 4.1.3 (preferably SUN SPARC 10). The model use will be well documented and will be provided by printed documents as well as by postscript files on the CD. The model is planned to be updated regularly in order to consider the evolution of the debris environment;

(c) To offer a CPU efficient information retrieval. Benchmark tests for the computation of flux to an ERS-1 type orbit (Sun-synchronous 780 km orbit) by the Analyst Application showed a performance of about 15 seconds on an IBM RS 6000 Workstation (comparable to a SUN SPARC 10) and slightly more when operating on a PENTIUM 66 MHz PC;

(d) To offer a simplified model upgrade and maintenance. Former models suffered from the fact that improvements of either breakup models or the deterministic database resulting from ground-based observations or space returned hardware could scarcely be implemented into the models. The semi-deterministic structure of the MASTER model allows for fast and simple implementation of those improvements when they become necessary.

Application Features of the MASTER model

The Analyst Application will enable the application of three different options, which are:

(a) The Kepler orbit option. This option allows the computation of Debris Flux (Engineering Application, also Meteoroid Flux) to any target object orbiting on a user defined Keplerian orbit. Input to this option is the user defined orbit (also eccentric), standard output is Debris Flux F_{Deb} as a function of impactor mass $\log_{10}(m_{imp})$, impact velocity v_{imp}, impact azimuth angle, impact elevation angle, target

revolution angle u and all first derivatives: $d(F_{Deb})/d(\log_{10}(m_{imp}))$, $d(F_{Deb}/d(v_{imp}))$, $d(F_{Deb})/d(\alpha_{imp})$ and $d(F_{Deb})/d(\delta_{imp})$. Angles α_{imp} and δ_{imp} are defined with respect to the spacecraft horizontal plane;

(b) The Inertial Volume option. This option allows the computation of Debris Flux to an inertial fixed unit sphere. Input to this option is the inertial fixed position of a unit sphere, standard output is the same as for the Kepler orbit (apart from $F_{Deb}(u)$ and $d(F_{Deb})/d(u)$);

(c) The Observatory option. This option allows the computation of Debris Flux within an Earth-fixed cone of sight (e.g. for a ground observing station). Input to this option is the user defined observatory location, direction and opening angle of the cone of sight and the desired altitude band. Standard output from this option is Debris F_{Deb} as a function of object mass $\log_{10}(m_{obj})$, object passage velocity v_{obj} (magnitude), range rate $v_{\rho,obj}$ (velocity component in the direction of the line of sight), cross rate $v_{\perp\rho,obj}$ (velocity component perpendicular to $v_{\rho,obj}$), passage azimuth angle α_{obj}, passage elevation angle δ_{obj} and the related derivatives of Debris Flux F_{Deb}. Angles α_{obj} and δ_{obj} are defined in the plane perpendicular to the line of sight.

Data files containing object-related information such as orbit, source and an identifier can be generated optionally and allow the generation of numerous further statistics. The model indicates that the debris flux to which a spacecraft of a given orbit is exposed strongly depends on its altitude and inclination. The flux resulting from the trackable population shows the well-known maxima for objects at altitudes around 800-1,000 km and around 1,500 km. The impact probability increases with growing target orbit inclinations and reaches its maximum of about 7×10^{-6} impacts per square metre per year at about 100° inclination. The flux resulting from objects larger than 1 cm is about a factor of 20 larger. The dependence on target orbit semi-major axis is, in general, the same as observed for the 10 cm population, though the cut-off at 7,350 km and 7,800 km is more moderate. The maximum flux of about 14×10^{-4} impacts per square metre per year is reached at about 110° inclination.

Future increase of orbital debris and prevention of additional debris generation

As a result of the progressive understanding of the orbital debris issue, in particular concerning the dynamics of the debris distribution in space and time and its propagation in the future, attention has focused on the question: Which measures can to be taken economically to prevent a possible collisional cascading effect in Earth orbit?

In order to assess the necessity and effectiveness of debris mitigation measures a number of studies have been performed within the last few years (A/AC.105/565/Add.2). Currently a study is being performed, which is based on the above-mentioned analysis and concentrates on the following issues:

(a) Actual debris mitigation measures planned or discussed with their time dependent step-wise introduction;

(b) Development of a new traffic model, which represents a more realistic scenario concerning upcoming mission types, launches, launch procedures etc. and which also describes in a practice-oriented way the common availability and utilization of debris mitigation measures;

(c) Consideration of graveyard orbits for the altitude region between LEO and GEO.

For this purpose all new data (e.g. surface impact data, remote debris measurements, orbital fragmentations monitored from Earth) will be considered. Besides the existing methods and computer

simulations, which evaluate the long-term collisional cascading effect by statistical methods, a semi-deterministic method is used for the short- and mid-term analysis. This method enables an in-depth analysis of some frequently used altitude regimes in Earth orbit (e.g. 700-900 km, Sun-synchronous inclinations) with respect to their collisional sensitivity and the specific effectiveness of debris mitigation measures for these regimes.

C. Radar detection and measurement of orbital debris

The FGAN Tracking and Imaging Radar (TIRA) is primarily used to investigate methods and techniques for classification and identification of aircraft and satellites. To a certain extent TIRA is additionally used to gain radar data of orbital debris. To this end two modes of operation have been developed: a tracking mode of operation to measure selected objects in LEO, GSO, and GTO and a beam-park mode of operation to collect data on the population of space objects in defined space volumes.

TIRA consists of a narrow-band tracking radar and a high-resolution imaging radar. Both radars are supported from a 34 m parabolic antenna. Methods and algorithms have been developed to analyse narrow-band radar signatures, to compute radar images from high resolution radar data, and to estimate physical properties of space objects like size, shape, dimensions, intrinsic motion, mass, orbit and orbital lifetime. These methods and techniques need further improvement and refinement to cope with mid-size space debris.[6,7,8]

Determination of physical characteristics of space debris

The objective of a NASA/FGAN joint research investigation (DARA Contract, 1/90-6/95) is to characterize and compare the parameters stated above for different types of breakups, i.e. from collisions and from explosions. At present TIRA measurements of 30 debris objects (size larger than 50 cm) and of six small metal spheres of the NASA experiment ODERACS (orbital debris calibration spheres, diameter of 5 cm, 10 cm, and 15 cm) are analysed. A statistical analysis of measured radar cross section (RCS) and a comparison with NASA results derived from effective areas of infrared, optical, and radar measurements is part of this study.[9,10]

Radar detection of mid-size space debris

The main objective of an ESA study (ESA/ESOC Contract, 2/93-12/94) focuses on the investigation of modifications to the L-band tracking radar of the TIRA system to detect and track mid-size space debris (size class ranging from 1-50 cm) in LEO for the improvement and verification of present space debris environmental models.

Several approaches to search for small targets at high ranges in defined space volumes and improvements of the signal-to-noise situation of the tracking radar were analysed. Based on the findings, concepts for hardware modifications together with requirements for signal and data processing algorithms were developed to detect mid-size space debris in the beam-park mode of operation.[11]

Reentry predictions of high-risk space objects

The objective is to provide the Federal Minister of the Interior with reliable predictions of reentry windows (time and ground track), estimations of object's attitude and risk assessments during reentry of high-risk space objects. Within cooperation agreements FGAN provided ESA/ESOC tracking radar measurements of high-risk space objects to support European reentry predictions.[12]

D. Shielding and impact analysis

Due to the pending situation of the European contribution to the international space station programme, the activities in the field of shielding and impact analyses in Germany have been reduced.

There are a few ESA/ESTEC funded studies. Two studies are executed by the Ernst Mach Institute (EMI). One study is investigating the conditions of catastrophic failure of pressurized vessels under debris impacts. The other is on experiment simulation of debris impacts on EURECA and the Hubble space telescope. Another ESA/ESTEC study with the Battelle Research Institute is on the improvement of shape charge techniques for hypervelocity impact simulations. These techniques are used for simulation of impacts with more realistic debris particle shapes, e.g. cylindrical particles with a mass of about 1 gram at velocities higher than 11 kms^{-1}. Besides the use of shape charge techniques, the light gas guns, et cetera, the facilities of EMI are used for defined reproducible simulation tests. Some industry-funded investigations by DARA are related to space debris protection measures of pressure vessels.

According to the DARA strategy, more detailed investigations in the field of impact phenomena analysis and shielding measures are planned.

Notes

[1]See the reports of the last two workshops by D. Alwes and K. U. Schrogl in Zeitschrift für Luft- und Weltraumrecht 1 (1993), pp. 83-88 and 1 (1994), pp. 74-79.

[2]H. Klinkrad, "Collision risk analysis of low Earth orbits", World Space Congress, 29th COSPAR meeting, Washington, D.C., September 1992 (paper No. B.8-M.2.07).

[3]H. Sdunnus and H. Klinkrad "An introduction to the ESA reference model", in Proceedings of the First European Conference on Space Debris, Darmstadt, Germany, April 1994 (ESA SD-01).

[4]H. Klinkrad, H. Sdunnus and J. Bendisch, "Development status of the ESA space debris reference model", 30th COSPAR meeting, Hamburg, July 1994.

[5]H. Sdunnus and others, "Application features of the MASTER debris model developed for ESA", 45th IAF Congress, Jerusalem, October 1994 (IAA-94-IAA.6.4.690).

[6]D. Mehrholz, "Space object observation with radar", in Advances in Space Research: Space Debris, vol. 13, No. 8, 29th COSPAR meeting (Plenary), Washington, D.C., August-September 1992.

[7]D. Mehrholz, "Potentials and limits of space object observations and data analyses using radar techniques", in Proceedings of the First European Conference on Space Debris, 1993 (ESA SD-01), pp. 59-64.

[8]K. Magura and D. Mehrholz, "Measurement and analysis techniques for satellite observations used at FGAN-FHP", FGAN-FHP Technical Report, 8-93 (Wachtberg-Werthhoven, December 1993).

[9]L. Leushacke and D. Mehrholz, "Determination of physical characteristics of space debris", Intermediate Reports 1-4, DARA Contract No. 50 ST 9003 (Wachtberg-Werthhoven, FGAN-FHP, 1991-93).

[10]L. Leushacke and D. Mehrholz, "ODERACS; intermediate summary of experiments and analyses at FGAN-FHP", ODERACS News Roundup, No. 8 (20 April 1994).

[11]L. Leushacke, and others, "Radar detection of mid-sized space debris", FGAN-FHP Technical Reports, 7-93, 6-94 (Wachtberg-Werthhoven, October 1994).

[12]D. Mehrholz and K. Magura, "Radar tracking and observation of noncooperative space objects by reentry of SALYUT-7/KOSMOS-1686", in The Reentry of Salyut-7/Kosmos-1686: Proceedings of the International Workshop, ESOC, Darmstadt, Germany, August 1991 (ESA SP-345).